3.34 RESULTS FOR BALLISTICS

The following assessment of ballistics is based upon comparisons between modeled trajectories in S&TI and T&E reports and trajectories obtained with *RADGUNS* v.1.9 for 23-mm projectiles and v.2.0 for 57-mm projectiles. Results are listed by caliber in Tables 3.34-1 and 3.34-2.

TABLE 3.34-1. Results for 23-mm Ballistics.

Data Source	Major Conditions	Statistical MOEs	Results
Reference 7	Point mass simulation of trajectory	Difference in downrange and altitude values after 10 s TOF	50.45 m downrange 30.94 m altitude
Reference 11	Point mass simulation with measured parameters	Difference in downrange and altitude values after 10 s TOF	16.89 m downrange 16.08 m altitude
Reference 10	Point mass simulation of trajectory	Difference in downrange and altitude values after 10 s TOF	6.33 m downrange 3.96 m altitude

TABLE 3.34-2. Results for 57-mm Ballistics.

Data Source	Major Conditions	Statistical MOEs	Results
Reference 11	Point mass simulation with measured parameters	Difference in downrange and altitude values after 10 s TOF	35.12 m downrange 22.71 m altitude

3.34.1 Assessment — Case 1

Ballistic trajectories generated by *RADGUNS* v.1.9 for the 23-mm projectiles were compared to trajectories listed in Reference 7, Reference 10, and Reference 11. *RADGUNS* v.2.0 was used to generate the trajectory of a 57-mm projectile for comparison against Reference 11.

<u>Test Data Description.</u> Reference 11 presents findings from the Static Ballistic Verification Tests performed at Aberdeen Proving Ground in December 1973 and at White Sands Missile Range in March and June 1974 in support of the Joint Test for Probability of Hit by Antiaircraft Guns (Reference 11). Gun-pointing angles, muzzle velocity, and radial velocity and downrange versus time were measured. Instrumentation included velocimeters, ballistic cameras, MIDI radar, and a system of digital encoders and optical auto-collimators. Both single-round and burst measurements were taken. Values for nominal projectile diameter, length, weight, muzzle velocity, axial moment of inertia, transverse moment of inertia, center of gravity, twist of rifling, lift factor, yaw drag factor, and ballistic coefficient are presented. Drag coefficient as a function of Mach number is also presented and was obtained by solving the ballistic equation inversely for the drag coefficient, given measured velocity and mass values. Simulated trajectories for both 23-mm and 57-mm projectiles are given for a firing elevation angle of 33.75 deg. These trajectories were computed by solving the modified point mass equations of motion shown in the report with the data values presented. Although the report advocates using a muzzle

velocity of 930 m/s for simulation of the 23-mm system (the value used in *RADGUNS*), a value of 970 m/s was used in the trajectory computation.

Reference 7 contains tables of projectile time-of-flight (TOF) versus pitch angle, velocity, downrange position, and altitude at gun elevation angles in 200 mil (11.25 deg) increments from 0 to 1600 mils (0 to 90 deg) for a 23-mm projectile. Trajectories were calculated by numerically integrating the two-dimensional equations of motion. A point mass model of the projectile was used with a nominal mass of 190.2 g and a muzzle velocity of 930 m/s. Magnus forces, Coriolis forces, and the earth's curvature were neglected in the modeling. The drag function shown appears to be the same function shown in the Reference 11 report, although no reference is made to its origin.

Reference 11 contains tables of projectile TOF in 0.1 s increments versus downrange and altitude for firing elevations from 0 to 1600 mils in 100 mil increments. Trajectories were calculated by numerically integrating the two-dimensional equations of motion using an approximation of the drag function shown in Reference 11.

Validation Methodology. In *RADGUNS* v.1.9, subroutine BLDTAB constructs a firing table of projectile TOF in 0.1 s intervals versus downrange position and altitude at firing elevations from 0 to 90 deg in 5 deg increments. The trajectory of each round at a given time is computed by linearly interpolating between points in this table. When a projectile is fired, simulation time is temporarily suspended, and the projectile is moved ahead in 0.1 s increments until the estimated time of closest approach is found (to within 0.1 s). The position and velocity of the round and the estimated time of closest approach are then passed to subroutine HITPRB for the calculation of probability of hit and kill for the round.

A 23-mm system was simulated in *RADGUNS* v.1.9 using the FIRET simulation type. This option generates a firing table named FT23.DATA. The trajectory of a round fired at an angle of 33.75 deg was obtained by interpolating between the values calculated at firing angles of 30 and 35 deg.

In *RADGUNS* v.2.0, projectiles fly out in simulation time (time is no longer suspended). The FIRET option does however output a firing table for the specified system. A 57-mm system was simulated with the FIRET option. The trajectory for a firing angle of 33.75 deg was obtained by interpolating between the values contained in file FT57.DATA for firing angles of 30 and 35 deg.

Results for 23-mm Ballistics

Figure 3.34-1 shows the trajectories for a firing elevation of 33.75 deg given in References 11, the Reference 7, and the Reference 10, and the trajectory obtained with model version 1.9. The difference between the downrange and altitude values generated with the model and the values shown in the references are listed in Table 3.34-3 for five TOFs. After a 10 s TOF, the projectile is well beyond the tactical range of the system simulated.

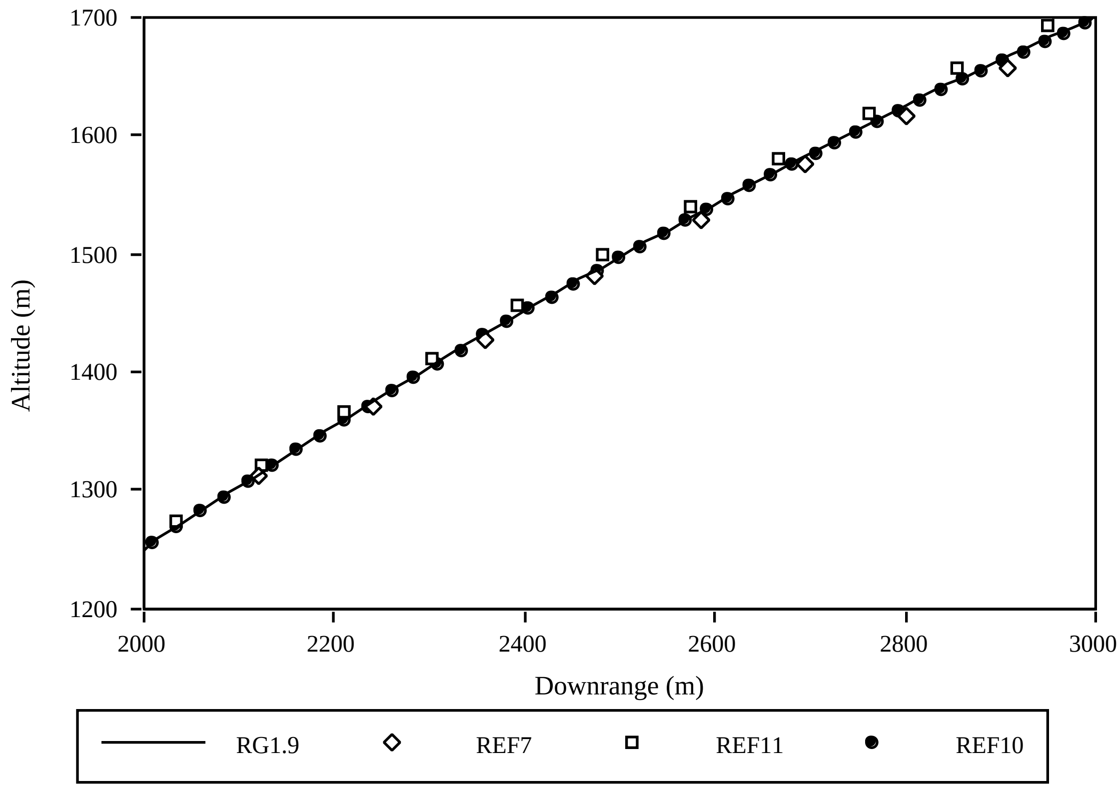

FIGURE 3.34-1. 23-mm Trajectory, Firing Elevation = 33.75 deg.

TABLE 3.34-3. Comparison of Model and Reference 7 Trajectories.

	REF7		REF11		REF10	
TOF (s)	**D Range (m)**	**D Altitude (m)**	**D Range (m)**	**D Altitude (m)**	**D Range (m)**	**D Altitude (m)**
2	-2.97	-2.02	30.26	20.38	-0.62	-0.48
4	-8.88	-5.85	33.83	23.41	-0.85	-0.65
6	-24.16	-15.01	29.85	21.84	-2.33	-1.64
8	-38.01	-23.36	23.79	19.23	-3.80	-2.58
10	-50.45	-30.94	16.89	16.08	-6.33	-3.96

RADGUNS replicates the most current intelligence to a high degree of accuracy. Differences between the model and the data given in Reference 11 may be attributable to the different muzzle velocities used, as well as the differences in the drag functions implemented in the two models.

Results for 57-mm Ballistics

Figure 3.34-4 shows the 57-mm trajectory for a firing elevation of 33.75 deg given in Reference 11 and the trajectory obtained with model version 2.0. Table 3.34-4 shows the difference in modeled and reference downrange and altitude values.

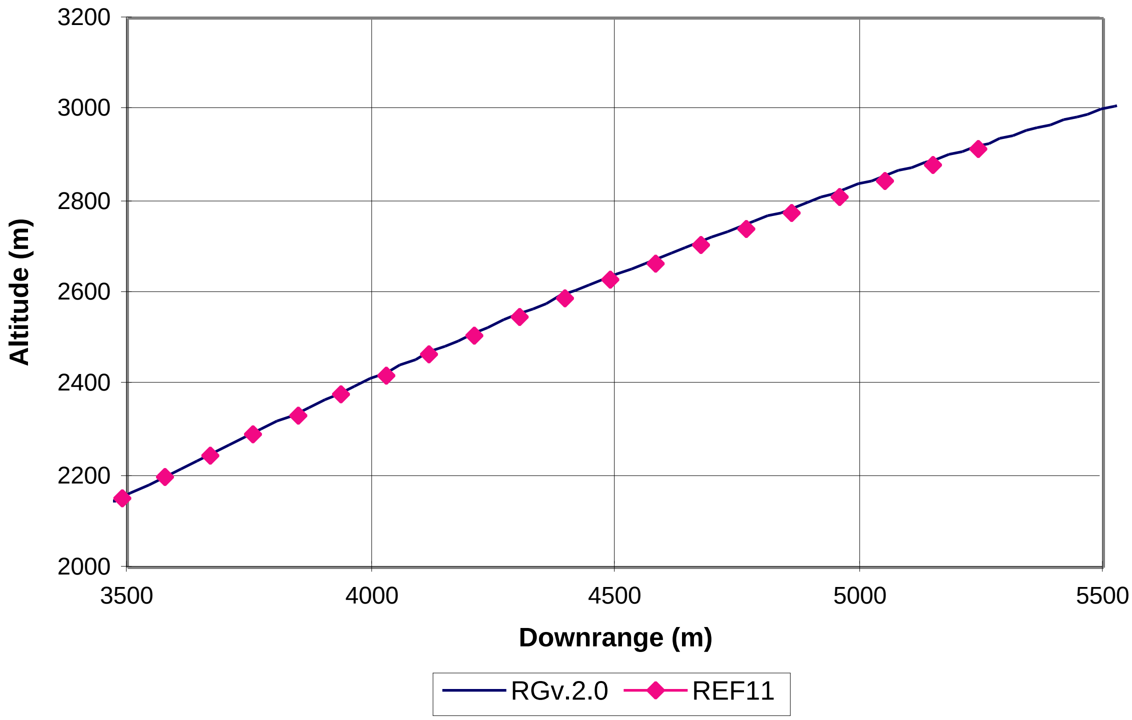

FIGURE 3.34-2. 57-mm Trajectory, Firing Elevation = 33.75 deg.

TABLE 3.34-4. Comparison of *RADGUNS* 57-mm Trajectory and Reference 11 Data.

	Difference (m)	
TOF (s)	**Downrange**	**Altitude**
2	-10.60	-6.92
4	-20.41	-13.22
6	-25.99	-16.83
8	-32.32	-20.61
10	-35.12	-22.71

Conclusions for 23-mm Ballistics

For a firing elevation of 33.75 deg, the model predicts a trajectory that falls between those shown in Reference 7 and Reference 11. The model accurately predicts the trajectory listed in Reference 10.

Conclusions for 57-mm Ballistics

MDR 95-011 described an error in the version 1.9 implementation of the drag function for 57-mm projectiles. This anomaly caused the model to consistently predict higher altitude and longer downrange values than those listed in Reference 11 for a projectile fired at an elevation angle of 33.75 deg. The difference between the modeled trajectory and the trajectory listed in the reference increased as TOF increased, reaching 209.8 m in downrange and 132.9 m in altitude after 10 s. This anomaly was corrected in version 2.0; the model and reference trajectories now differ by 35 m in downrange and 23 m in altitude after 10 s time of flight. Differences of this magnitude may be attributable to differences in the drag functions implemented by the two models.